Lorentz Force Detuning Compensation for XFEL Pre-series Cavities at CMTB Test Stand in DESY.

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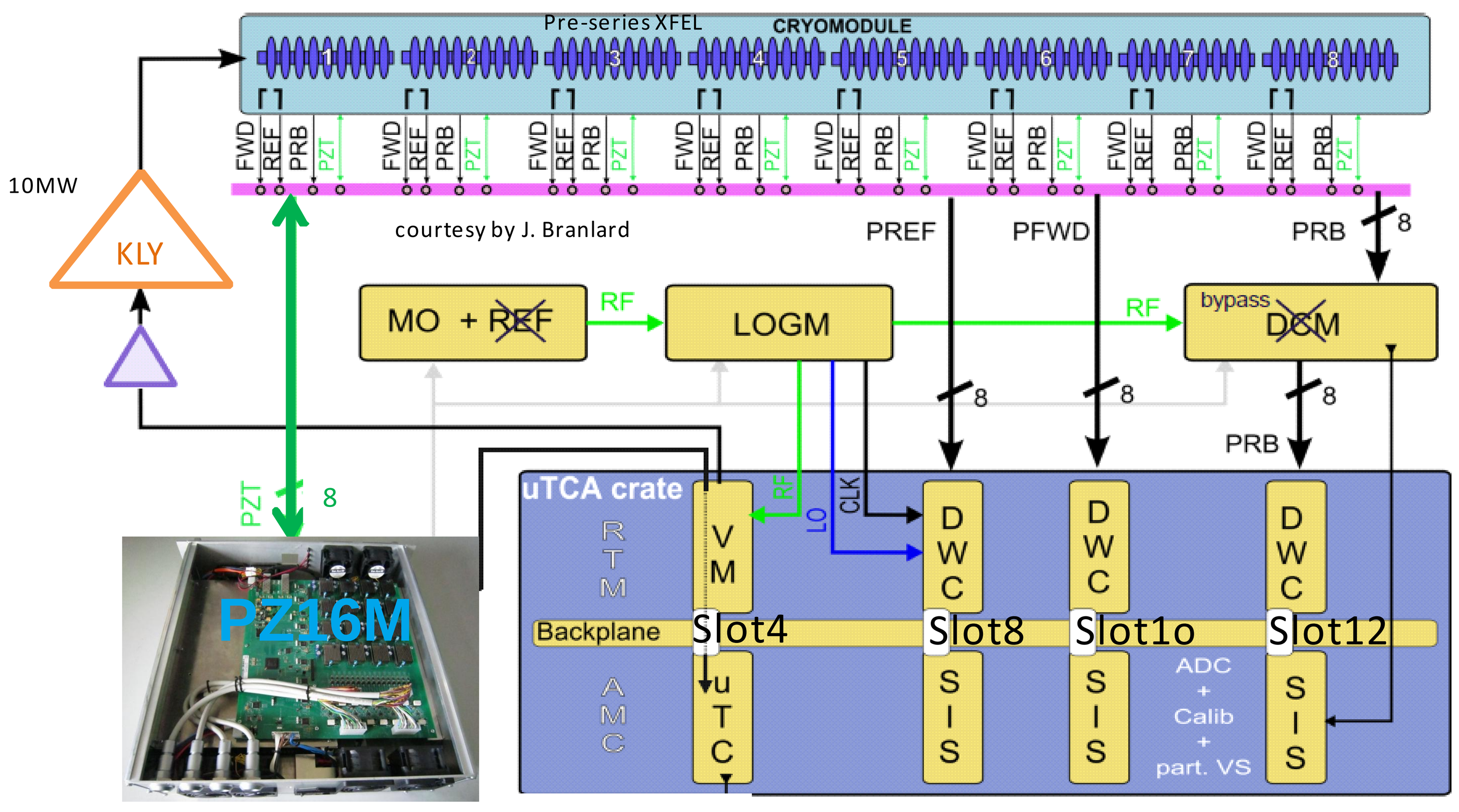
Abstract

Operation of superconducting resonant 9-cell TESLA cavities requires sophisticated setup and calibration procedures. When operating at high gradients, SRF cavities experience mechanical deformation mainly due to Lorentz forces resulting in a frequency shift of the cavity natural resonance frequency (1.3 GHz). The paper briefly presents the setup and calibration procedures to allow high gradient operation of the superconducting resonant cavity. **It also shows the first results of several seconds of operation of a cavity installed inside one of the pre-series modules for XFEL at the CMTB test stand. This cavity reached gradients of more than 40 MV/m. Lorentz force detuning effects (> 700 Hz) were compensated using the piezo tuner and its control electronics** during the flattop region of 1.3 ms RF field pulse.

System components

A pre-series XFEL cryomodule has been installed at cryomodule test bench (CMTB) in DESY. The accelerating module has been connected to RF power source and conditioned using both coupler antennas and cavity slow tuners. After that, the LLRF control system has been connected to 10 MW RF power source - klystron. The fast frequency tuners equipped with double piezo elements (assembled inside cryomodule) have been connected to piezo control system (PZ16M). For each cavity, the first piezo element has been configured as actuator mainly for Lorentz force detuning compensation, while the second one as a cavity mechanical vibrations sensor.

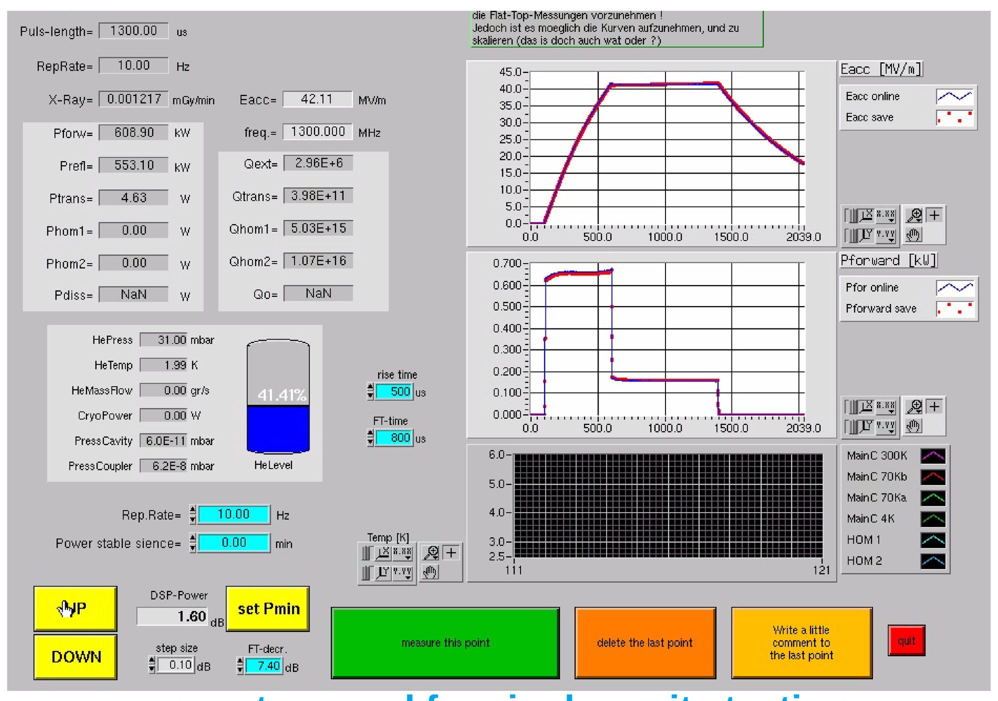


Accelerating field calculation using calibrated power

The measurement were performed on the existing DESY cryomodule test stand (CMTB) as an extension of the standard measurements for XFEL cryomodules. The accelerating field calculation is taken from the following equation:

$$E_{acc} = k_t \cdot \sqrt{P_{tr}}$$

where k_t is the calibration coefficient computed at the small gradient calibration point (< 5 MV/m). The peak power (P_{tr}) is read by a power meter. Thus, having a constant flattop allows for a more precise calibration. Without piezo compensation of Lorentz force detuning, the measurement accuracy of the accelerating field is compromised for gradients above 30 MV/m.



operator panel for single cavity testing

Cavity detuning measurement and piezo control setup

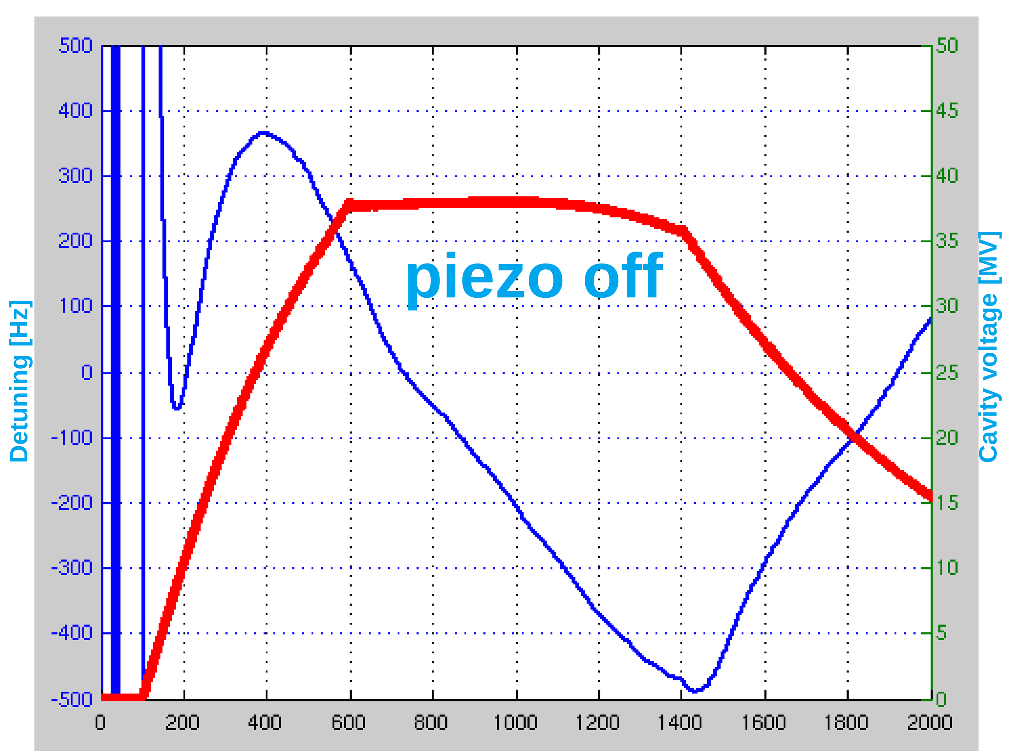
The cavity detuning is calculated based on the standard electrical-mechanical model of the cavity, re-written in Cartesian coordinates (using In-phase and Quadrature components of the complex RF field vector):

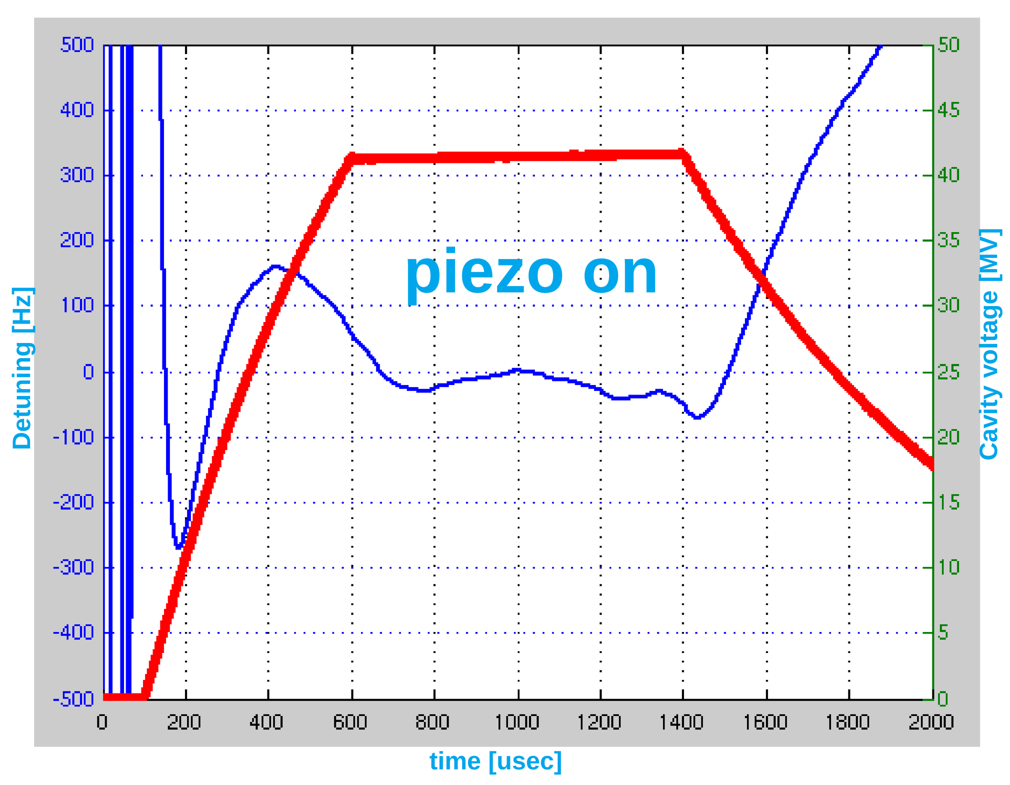
$$\Delta\omega = \frac{-\left(\frac{dI_{probe}}{dt} - coeff \cdot I_{pfor}\right) \cdot Q_{probe} + \left(\frac{dQ_{probe}}{dt} - coeff \cdot Q_{pfor}\right) \cdot I_{probe}}{I_{probe} \cdot I_{probe} + Q_{probe} \cdot Q_{probe}}$$

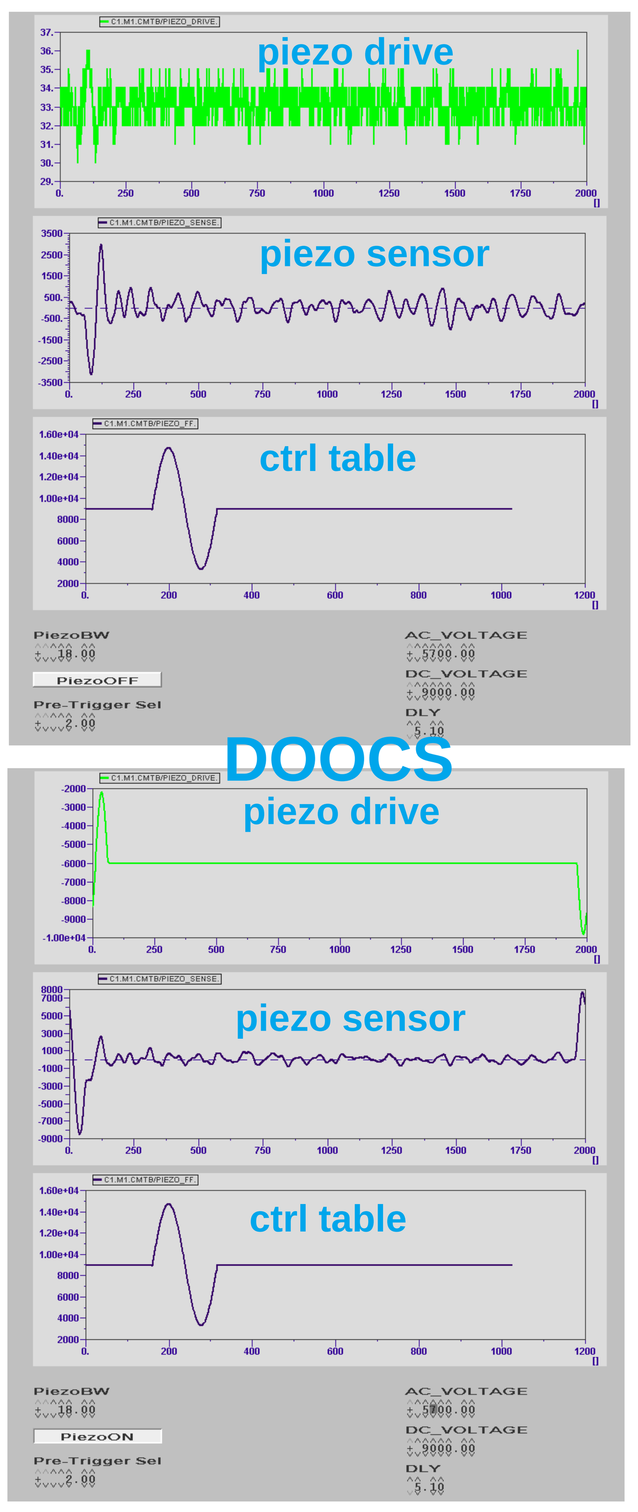
where *coeff* is the cavity half bandwidth component.

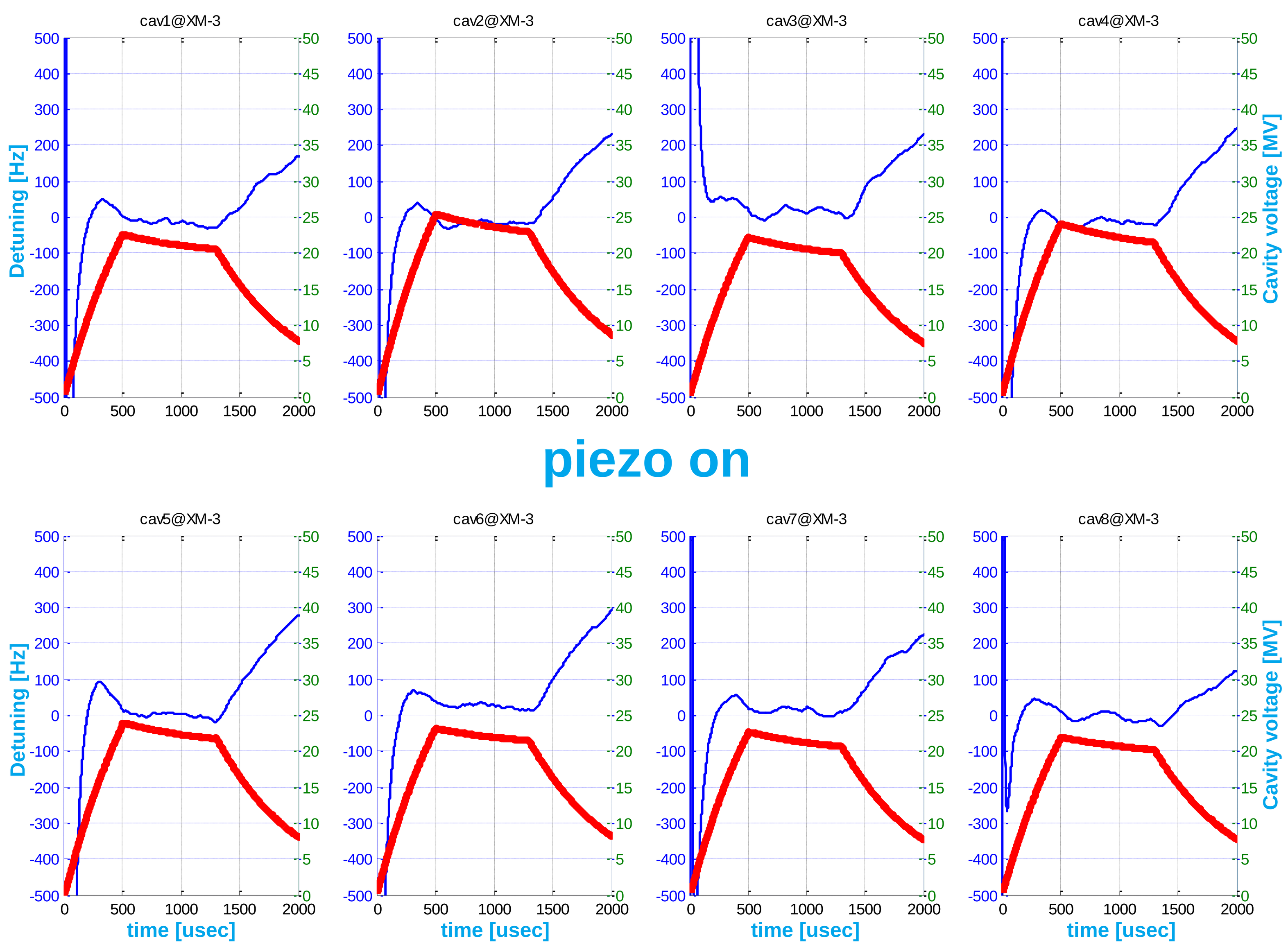
The piezo compensation pulse range has been setup to start 12 ms before and finish 12 ms after the RF field pulse. A bipolar, sinusoidal-like excitation with optimized AC, DC voltages (<140Vpp), frequency range (200 Hz) and adjusted delay (6 ms before RF) has been used to optimize the LFD compensation.

Lorentz force detuning compensation









In order to compensate detuning that exceeds more than 3 times the cavity bandwidth (E_{acc}>42MV/m), a single pulse sinusoidal excitation of 2/3 of full range (AC~90 V_{pp}) amplitude has been applied with the piezo driver. Stable operation, without cavity quench, was recorded over several seconds.

As a proof of principle, piezo compensation has been applied for all 8 cavities installed inside XM-3 accelerating module. The average gradient has been setup to 22 MV/m. The initial detuning of 100 Hz has been decreased up to the level of less than 10 Hz.

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Abstract ID: 55, LLRF 2013, Lake Tahoe, California, 1-4 October 2013